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EVALUATION OF THE COMBAT EDGE AND MBU-20/P MASK SYSTEM DURING +GZ IMPACT ACCELERATION

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

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An experimental effort was conducted on a vertical deceleration tower to determine the compatibility of the COMBAT EDGE & MBU-20/P mask system with a HGU-55/P helmet in a +Gz impact acceleration environment. Tests were conducted at 10 G impact levels and a MBU-12/P mask with a HGU-55/P helmet was used as a baseline for comparison. The test results were used to evaluate the structural integrity, mask stability, and weight and center-of-gravity effects of the COMBAT EDGE & MBU-20/P system. Inertial property results indicated that the COMBAT EDGE mask system was approximately 0.4 lbs heavier and had lower center-of-gravity compared to the baseline. Results indicated that there were no major problems with the structural integrity of the COMBAT EDGE mask system during impact. Mask stability results indicated that the COMBAT EDGE mask displaced downward twice the distance the baseline mask did during impact. Further evaluation of the mask indicated that the adjustment webbing guide paths would need modifications to prevent slippage.

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PREFACE

An experimental effort was conducted to evaluate the structural integrity, stability, and inertial properties of the COMBAT EDGE & MBU-20/P mask system with a HGU-55/P helmet during +Gz impact accelerations. Test results were used to compare the system to a baseline system consisting of a MBU-12/P mask with a HGU-55/P helmet. The experimental tests were conducted on the Armstrong Laboratory's Vertical Deceleration Tower at WP-AFB OH. The effort was conducted for HSC/YA at Brooks AFB TX.

All tests described in this report were conducted by the Escape and Impact Protection Branch of the Armstrong Laboratory. Facility and data acquisition support were provided by DynCorp under Contract F33615-91-C-0531.

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INTRODUCTION

Research to provide pilots with the proper equipment for G-protection has been on-going for several decades. This research is on-going because improving flight control systems are allowing pilots to fly their mission profiles higher and faster which increases the physiological load on the human body and in particular, the cardiovascular and respiratory systems. To help improve pilot performance and reduce physiological loads, the COMBAT EDGE & MBU-20/P mask system has been developed to provide the pilot a positive pressure breathing and mask coupling system which would help reduce the chance of G-induced loss of consciousness during a high-G maneuver.

The COMBAT EDGE system consists of a low profile mask, an occipital bladder to seal the mask during pressure breathing, a regulator, and additional torso anti-G systems. Improvements to the mask and bladder system have necessitated additional testing of these components in an aerospace environment.

At the request of the Life Support Systems Program Office at Brooks AFB, the Armstrong Laboratory's Escape and Impact Protection Branch (AL/CFBE) at Wright Patterson AFB was requested to test the improved COMBAT EDGE and MBU-20/P mask system with an HGU-55/P helmet in an impact acceleration environment simulating the forces the system may experience during the catapult phase of an emergency escape. The test objectives were to evaluate the system's structural integrity, stability, and inertial properties during a +Gz impact acceleration. Results were compared to a baseline system consisting of a MBU-12/P mask with a HGU-55/P helmet.

METHODOLOGY

To evaluate the integrity, stability, and inertial property effects of the COMBAT EDGE and MBU-20/P mask system (from here on referred to as the COMBAT EDGE system) in an ejection environment, a series of short duration, +Gz impact acceleration tests were conducted using the AL/CFBE Vertical Deceleration Tower (VDT) and the Advanced Dynamic Anthropomorphic Manikin or ADAM. The VDT, shown in Figure 1, provided a +Gz impact acceleration that produces a biodynamic response approximating the ACES II ejection catapult response. The ADAM, a specialized instrumented manikin, was used to estimate the biodynamic response of humans in the dynamic impact environment.

The VDT functions to simulate an ejection seat catapult acceleration pulse by producing a +z-axis (inferior to superior) impact acceleration using a hydraulic decelerator. A seat pan and seat back configuration are mounted to a carriage which can move vertically on a pair of guide rails. The carriage can be hoisted to a specific height and then allowed to free-fall. A contoured plunger mounted on the back of the carriage is then guided into a cylindrical reservoir filled with water. The action of the plunger displacing the water in the reservoir generates the deceleration or impact profile of the carriage. This profile is then transmitted to a subject sitting in the carriage mounted seat. The profile is shaped by the height of the carriage at free-fall (controlling the magnitude of the impact pulse), and by the shape of the plunger (controlling the rise-time of the impact pulse). The 10 G pulse used for this program is shown in Figure 2.

The ADAM was restrained in a seated posture to the VDT seat by a standard USAF lap belt and double shoulder strap configuration. The upper limbs were restrained to the thigh, and the lower limbs restrained in a vertical position using Velcro strapping. The seat back angle was set to 0°, and the plane of the headrest was in-line with the seat back. An un-cushioned, flat, rigid seat pan was used for all tests. The test facility was instrumented with load cells to collect seat pan loads and loads in the restraint system. Accelerometers were used to measure carriage and seat accelerations. The ADAM was instrumented to collect linear head and chest accelerations, and angular head and chest velocities. The ADAM cervical spine was also instrumented with a special six-axis Denton load cell to allow the collection of neck loads and torques generated at the occipital condyle or head/neck junction. The restraints

were pre-tensioned to 20 $\pm$ 5 pounds prior to each test. All accelerations, velocities, and forces were collected with a carriage-mounted automatic data acquisition system located above the seat assembly.

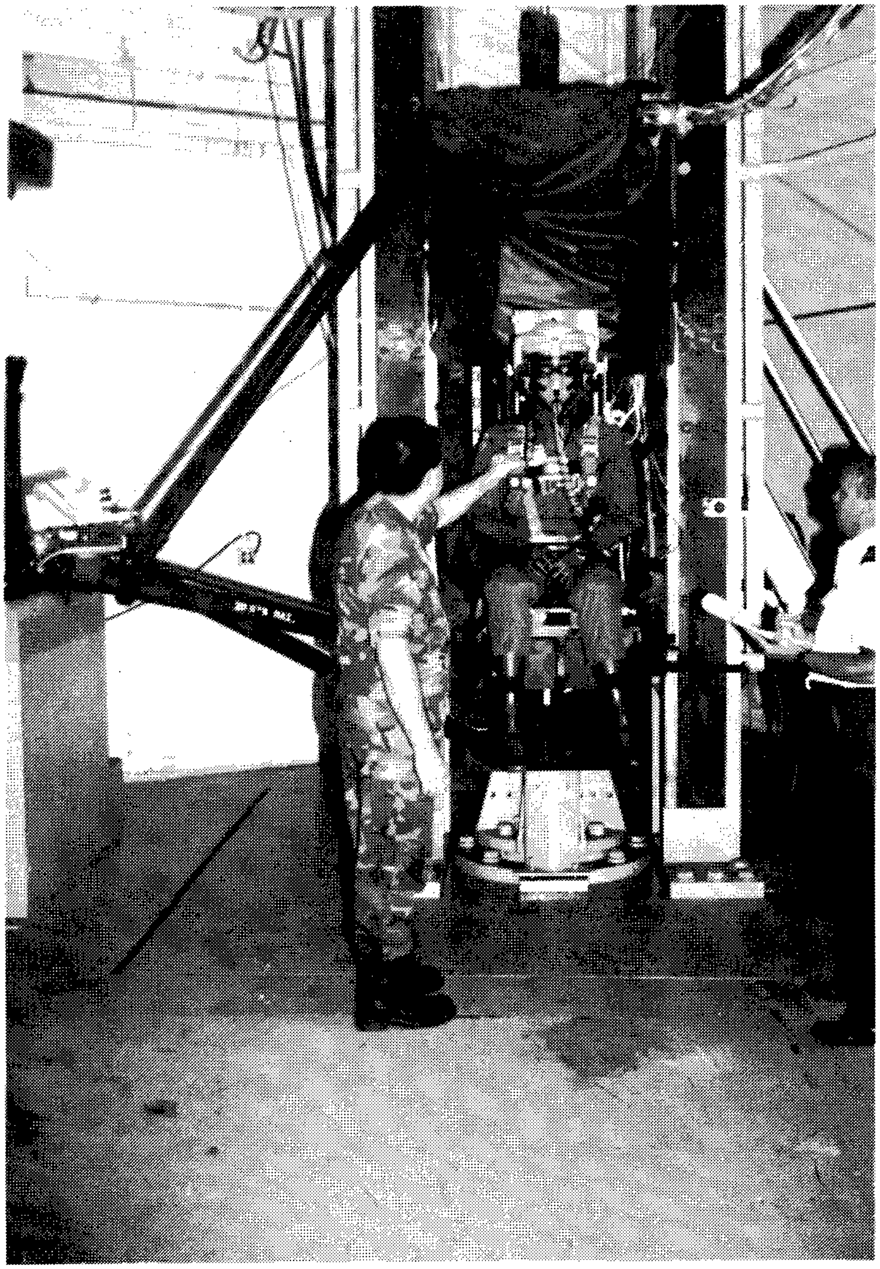

FIGURE 1. AL/CFBE VERTICAL DECELERATION TOWER (VDT)

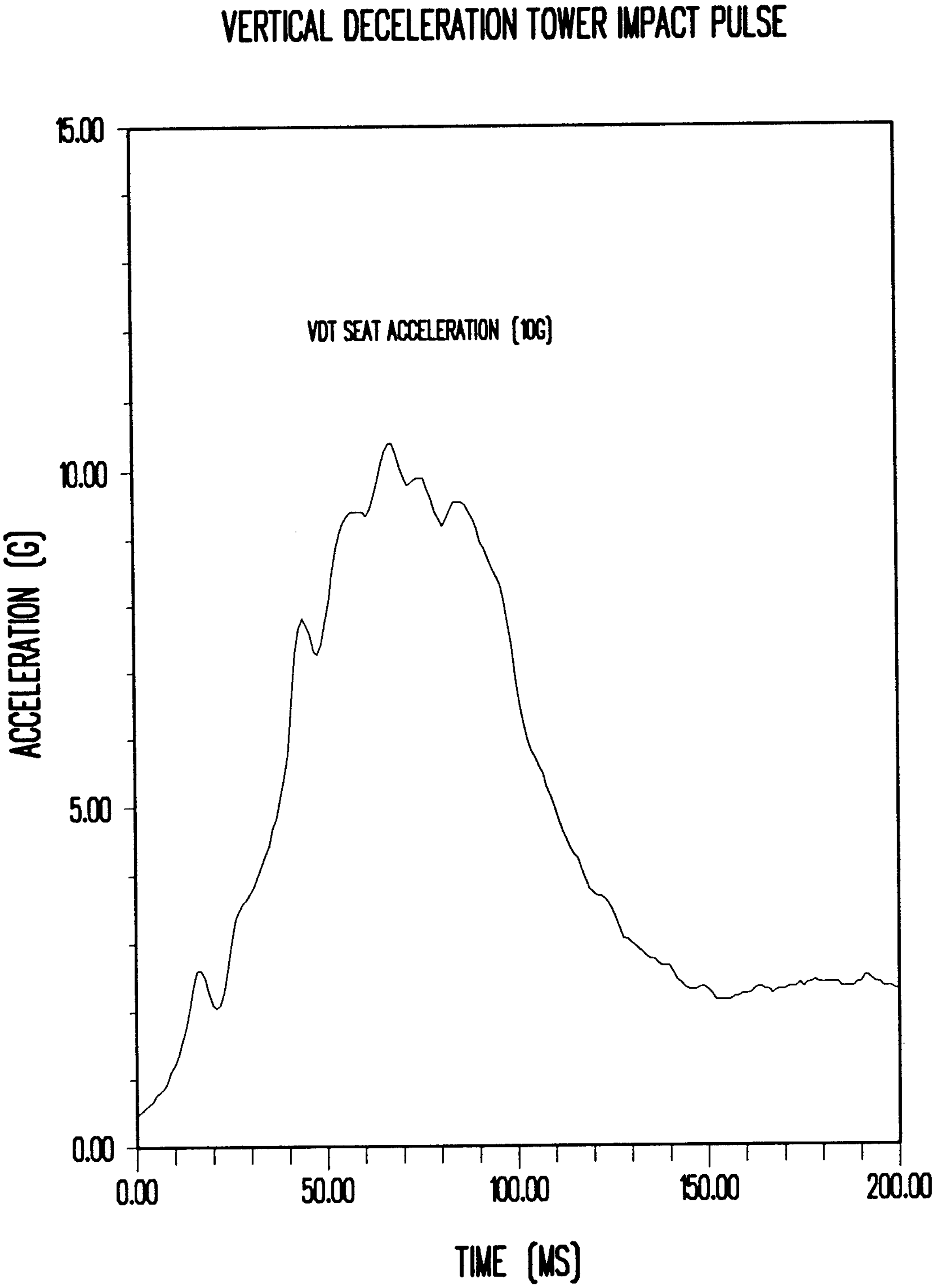

FIGURE 2. VDT 10 G IMPACT ACCELERATION PULSE SHAPE

In addition to the electronic data, motion analysis data was collected during each test using two different systems mounted on special supports attached to the carriage. Each test was documented with a KODAK high-speed video system. The single camera captured the detailed movements of the ADAM and the helmet/mask systems during the impact acceleration. In addition to the video coverage, a SELSPOT motion analysis system was used to track the displacement of targets on the carriage and the ADAM. The location of the targets is shown in Figure 3. The SELSPOT system utilizes two photosensitive cameras to track the motion of the infrared LED targets. By tracking specific points on the head and the mask during each test, the relative displacement of the mask during impact could be determined using the SELSPOT displacement data.

Prior to impact testing, the inertial properties, including weight and center-of-gravity (Cg), of the COMBAT EDGE system and the baseline were measured. This was accomplished in order to combine the inertial properties of the tested systems with those of the ADAM headform. By having the combined inertial properties, comparisons and relationships could potentially be established between the systems themselves, and between the inertial property parameters and the biodynamic response parameters of the ADAM. This procedure was completed by the Vulnerability Assessment Branch of the Armstrong Laboratory (AL/CFBE).

The impact tests were conducted using both the baseline helmet and mask, and the modified COMBAT EDGE system and an HGU-55/P helmet. The baseline system is shown in Figure 4, and the COMBAT EDGE system is shown in Figure 5. Approximately 5 tests were run with the baseline helmet at a 10 G impact level, followed by 6 tests with the COMBAT EDGE helmet system also at a 10 G impact level. The initial baseline series allowed verification and modification of procedures used to compare and contrast the two systems, including the measurement of mask slippage. A test matrix is shown in Table 1.

TABLE 1. COMBAT EDGE TEST MATRIX

Test Cell	No. of Tests	Helmet	O_2 Mask
A	5	HGU-55/P	MBU-12/P
B	6	HUG-55/P	COMBAT EDGE

Upon completion of the tests, the motion and displacement data, and the electronic data were analyzed using standard statistical methods. The weight and Cg data were compared to the baseline system and to the AL Head/Neck Weight and Cg Criteria. Slippage of the mask was estimated by analyzing its relative z-axis displacement as compared to the brow position on the ADAM.

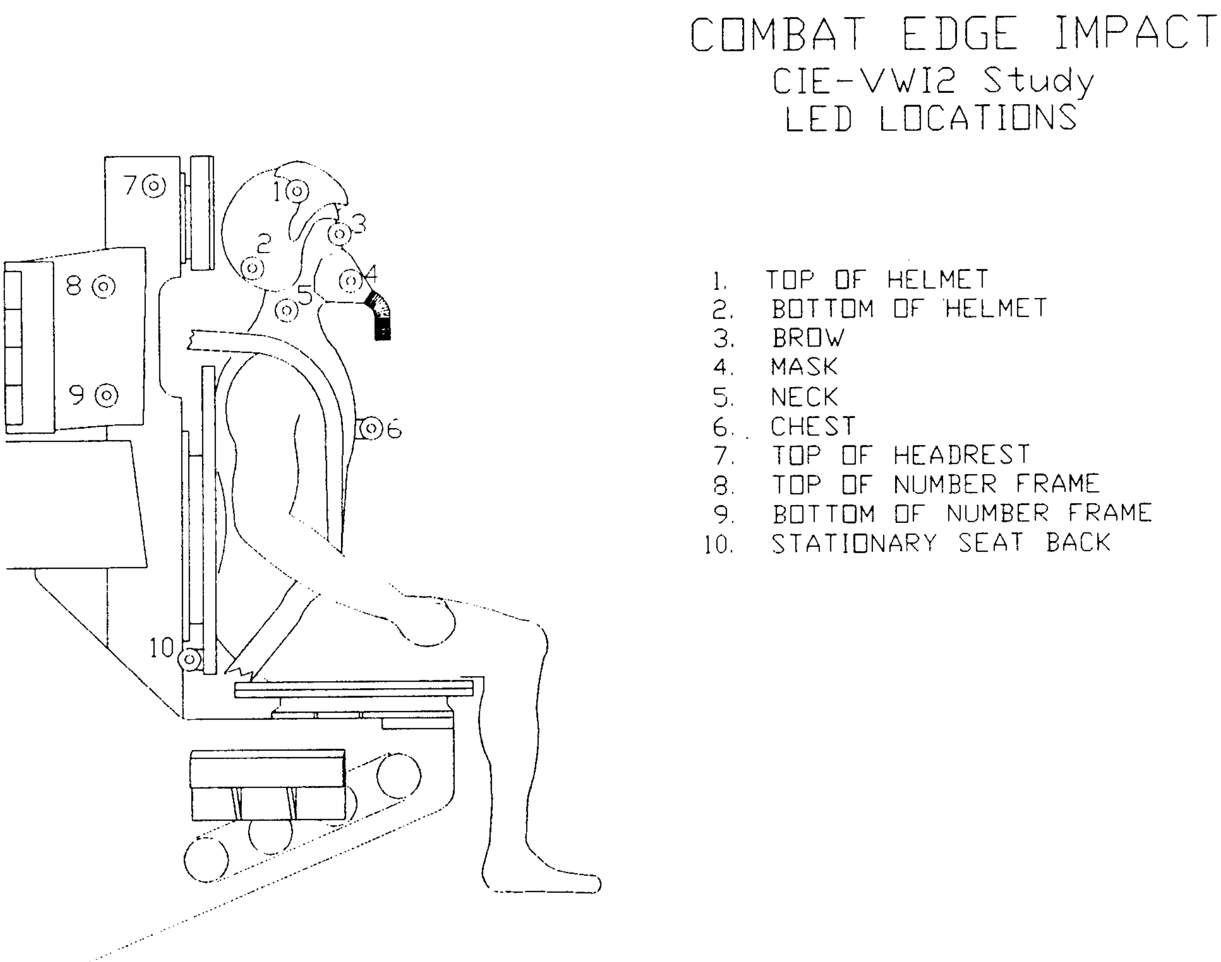

FIGURE 3. SELSPOT LED LOCATIONS FOR COMBAT EDGE IMPACT TESTING

FIGURE 4. HGU-55/P HELMET AND MBU-12/P MASK BASELINE SYSTEM

FIGURE 5. HGU-55/P HELMET AND COMBAT EDGE MASK SYSTEM

RESULTS

The specific objectives of this test program were to evaluate the structural integrity, mask stability, and inertial property effects of the new COMBAT EDGE and MBU-20/P mask system during vertical impact. The equipment was mounted on a HGU-55/P helmet and the results were compared to similar impacts conducted with a baseline system consisting of a HGU-55/P helmet and a MBU-12/P mask.

A part of the biodynamic evaluation of a head mounted system is the calculation of the inertial properties. All inertial property data is relative to the head anatomical axis system of the ADAM. This coordinate system is defined by a line connecting the right and left tragion (notch above ear canal) which is the y-axis, a line connecting the infra-orbital notch (bone ridge below eye) and the y-axis, and shifted equidistantly between the tragions, which is the x-axis, and a line perpendicular to the intersection of the y-axis and x-axis which is the z-axis. The intersection of all three axes forms the coordinate origin of the anatomical axis system. The axes system is shown in Figure 6.

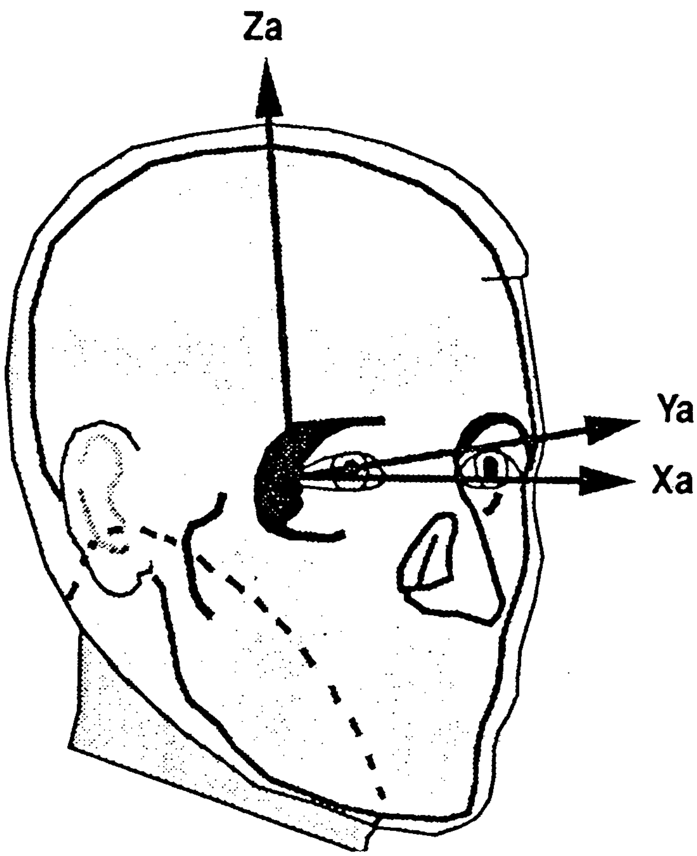

FIGURE 6. HEADFORM ANATOMICAL AXIS SYSTEM

A summary of the inertial properties of various headforms and various combinations of the ADAM headform, HGU-55/P helmet, MBU-12/P mask, and the COMBAT EDGE system are shown in Table 2. In the table, 55/P refers to the HGU-55/P helmet, CE refers to the COMBAT EDGE helmet bladder system, 12/P refers to the MBU-12/P mask, and 20/P refers to the MBU-20/P mask. All Cg values are referenced to the ADAM anatomical coordinate system. The systems with masks have a full hose wrapped to the right side of the ADAM neck. The ADAM headform inertial properties shown in the table are for the same headform used during calculation of the inertial properties of the additional systems shown in the table. The data shows that as you add equipment to the helmet, the weight will correspondingly increase. It should be noted that the weight of the helmet, COMBAT EDGE bladder, and MBU-20/P mask is under 4.0 lbs. The Cg data also shows logical shifts in the x-axis and z-axis values as systems are added to the baseline helmet. It should also be noted that the full COMBAT EDGE system with helmet has a Cg a little forward and below that of the baseline helmet and mask, and that both systems are acceptable relative to the USAF Interim Head/Neck Criteria as shown in Figure 7.

The structural integrity and mask slippage evaluation was also completed on the COMBAT EDGE system to determine the system's tolerance to +z-axis impact accelerations. The system had no structural failures during the 10 G impact test series, however, after the second test, is was documented that the retention straps or webbing on the MBU-20/P mask began to loosen and fray at the points where the straps interfaced with the mask structure. This can be shown in Figure 8. The slippage of the mask was quantitatively analyzed and compared to slippage in the baseline system using SELSPOT data. For each test cell, the relative displacement of the mask in the z-axis was measured by with reference to a point on the head (brow) also measured by SELSPOT. The difference between peak displacements of the brow and mask was calculated for each test and a mean and standard deviation calculated for each cell. Table 3 contains this data in addition to data for other parameters. The relative displacement data shows the COMBAT EDGE system to displace approximately 0.5 inches which is roughly twice the baseline system. This is most likely due to the mask webbing not keeping the mask structure secure against the face of the manikin during impact. It could also be due to small variations in the pre-test positioning and tightening of the mask.

The additional data in table 3 shows the biodynamic response of the ADAM with the baseline system compared to the ADAM with the COMBAT EDGE system. As the small variations in inertial properties would suggest, the biodynamic data indicates that there is little difference between the two systems. The COMBAT EDGE system having a larger compressive (z-axis) neck load compared to the baseline would be expected due to its slightly higher weight, however, both systems generate loads that are well below the 400 lb major injury threshold as determined by Mertz and Patrick. The angular velocity values are also well below the 20 to 30 rad/sec major injury threshold. The biodynamic data in table 3 indicates that there is no significant differences in the impact response of the two systems during a 10 G impact acceleration. Data indicates a trend for the neck loads to slightly increase and for no increase in forward head rotation.

TABLE 2. HEAD AND HELMET SYSTEM INERTIAL PROPERTIES FOR COMBAT EDGE PROGRAM

SYSTEM	WEIGHT OF SYSTEM (LBS)	WEIGHT WITH ADAM (LBS)	CENTER OF GRAVITY (IN)
Large Human Head		9.70	-0.28 , 0.00 , 1.32
Large ADAM Head		9.39	-0.32 , -0.03 , 1.01
ADAM + HGU-55/P	2.54	11.93	-0.46 , 0.21 , 1.13
ADAM + 55/P + CE	2.78	12.17	-0.59 , 0.31 , 1.17
ADAM + 55/P + 12/P	3.64	13.03	-0.39 , 0.12 , 0.86
ADAM + 55/P + 20/P + CE	3.81	13.19	-0.36 , 0.36 , 0.75

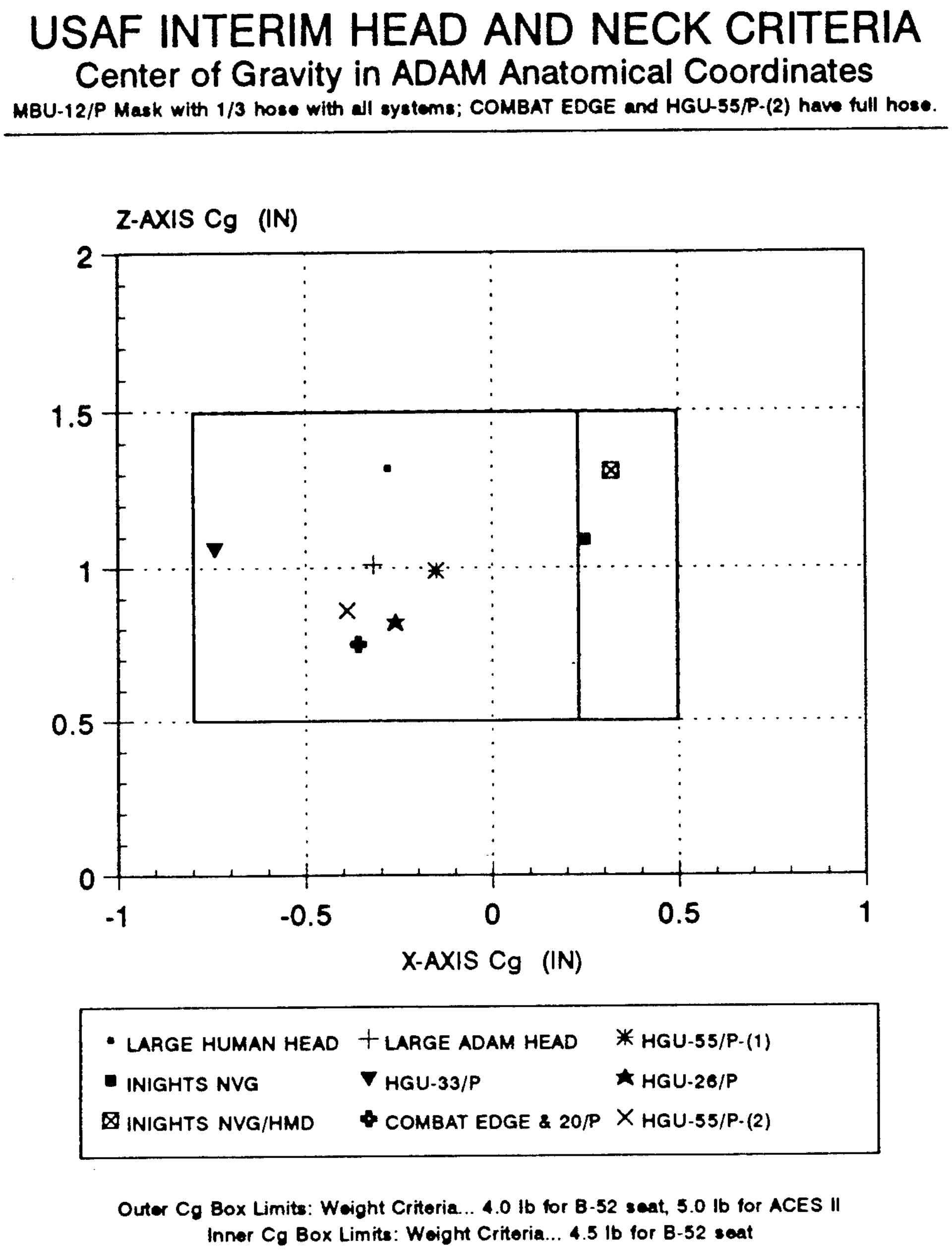

FIGURE 7. INTERIM HEAD AND NECK CRITERIA RELATIVE TO COMBAT EDGE AND BASELINE SYSTEMS WITH FULL HOSE

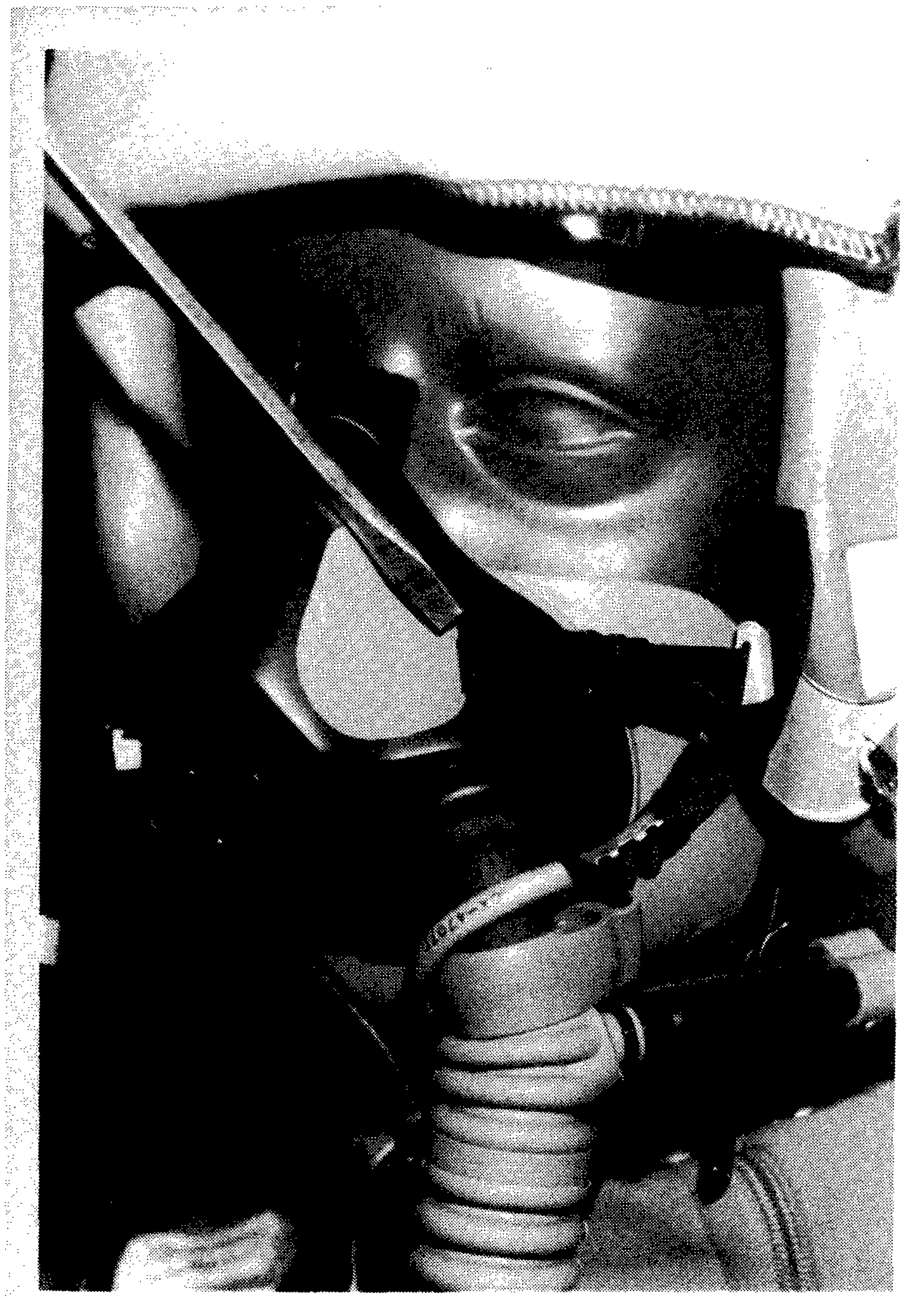

FIGURE 8. LOCATION OF FRAYED WEBBING ON COMBAT EDGE SYSTEM AFTER IMPACT

Table 3. Combat Edge Impact Program Data Summary

Helmet System		ADAM Z-Axis Head Accel (G)	ADAM Head Angular Vel (Rad/Sec)	ADAM Head Z-Axis Load (Lbs)	Relative Mask Disp. (In)
Cell A	Mean	13.95	4.24	155.48	0.233
(HGU-55/P, 12/P)	Std Dev	0.275	0.12	2.84	0.063
Cell B	Mean	14.08	4.18	160.67	0.479
(HGU-55/P, 20/P, CE)	Std Dev	0.188	0.15	2.7	0.035

CONCLUSIONS

Tests were conducted on the AL/CFBE VDT facility to evaluate the compatibility of the COMBAT EDGE mask system with an HGU-55/P helmet during positive vertical impact accelerations. The results were compared to similar impacts of a baseline system consisting of an HGU-55/P helmet and a MBU-12/P mask. The baseline helmet was subjected to 5 impacts and the COMBAT EDGE system was subjected to 6 impacts. All tests were conducted with the systems mounted on the head of an ADAM and at impacts of 10 G. Inertial property evaluation revealed the COMBAT EDGE system to be very similar to the baseline system being less than a half pound heavier. Both systems as expected meet the USAF Interim Head and Neck Criteria in terms of weight and center-of-gravity. The impact tests revealed little biodynamic difference between the two systems with the COMBAT EDGE system having slightly higher compressive neck loads as expected. The impact tests did reveal the need for a modification of the webbing that adjusts the mask pressure on the face because the z-axis displacement of the COMBAT EDGE MBU-20/P mask was approximately twice the displacement of the baseline mask system.

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